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Soil arthropod community in the olive agroecosystem: Determined by environment and farming practices in different management systems and agroecological zones

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ABSTRACT

Research on the relationship of the olive agroecosystem biodiversity with farm management and environment is limited, despite the importance of olive production for Mediterranean countries. In this study, we assumed less intensified olive orchard management to enhance soil arthropod community, and farm management and environmental factors to be important drivers shaping it. Soil arthropods were monitored seasonally for two years in organic, conventional and integrated olive orchards, located in hilly and plain agroecological zones of Crete, Greece. Farming practices, climate and landscape complexity were recorded. Two subgroups of functional taxa were defined, with respect to the prioritized agroecosystem services of biological pest control and nutrient cycling. Significant differences in arthropod community were found between agroecological zones for specific taxa, seasonal diversity indexes and functional subgroups. The group of climate, farming practices and landscape factors explained always a larger portion of arthropod variability, than management systems and agroecological zones together. Temperature, soil tillage, as well as relative humidity, appeared as the most important explanatory variables. Agroecological zones explained a biggest fraction of arthropod variability than management systems. Agricultural management and environment should be considered in the biodiversity assessment of the olive orchard agroecosystem.

1. Introduction

Olive production is a major agricultural, environmental and economic driving force for Mediterranean countries. Olive trees are cultivated within a variety of landscapes and agroecological zones, where management systems of different intensity are applied. Olive cultivation frequently follows a conventional agricultural protocol, especially in industrialised, modern olive orchards, which face ecological problems (Kabourakis, 1999; Volakakis et al., 2012). The biodiversity of agroecosystems where intensification takes place is led to impoverishment (Biaggini et al., 2007), while soil arthropod fauna is especially affected (Cotes et al., 2010; Ruano et al., 2004; Santos et al., 2007).

A major, related to above, concern is that enhanced agro-ecosystem biodiversity, when correctly assembled, provides several services, supporting soil fertility, crop protection and productivity (Altieri, 1999). The part of agro-biodiversity delivering such desired services, depending always on the stakeholder's objectives and priorities, is regarded as "functional" (Bàrberi, 2013; Moonen and Bàrberi, 2008). Soil arthropod community may well deliver substantial services in the olive agroecosystem, in terms of biological control of the olive fly (*Bactrocera oleae* (Rossi), Diptera: Tephritidae), the main olive pest worldwide (Daane and Johnson, 2010). In fact, several studies have shown that the predatory soil

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arthropod community can increase mortality on the Tephritidae pupae (Orsini et al., 2007). Another major service is nutrient cycling and decomposition, by litter fragmentation, grazing on microflora and improvement of soil structure (Reichle, 1977).

As a consequence of the decline of biodiversity, growing concerns arise for the sustainability of farming practices (Hole et al., 2005). Agri-environmental schemes, including less intensive farming systems, like organic, are considered important tools to combat the negative effects of intensive agricultural production (European Environment Agency, 2004). However, the assessment of the environmental effectiveness of such systems, often encounters methodological problems (Bengtsson et al., 2005; Ponce et al., 2011). Hole et al. (2005) pointed out several issues related to the problematic nature of different management systems comparison, with regards to their impact on biodiversity. They identified several universal problems, including the incorrect conclusions drawn due to lack of control for extraneous variation, such as the influence of landscape characteristics to community structure, identified as well by Bengtsson et al. (2005) and Gomiero et al. (2011). The short time-scale of studies, often limited to a single season/year, was also regarded as representing stochastic variability in community structure, rather than the differences resulting from farming regimes. On the other hand, factors such as location, climate, crop-type and species are listed as those influencing the effect of management system on biodiversity (Hole et al., 2005).

Another issue is the limited number of studies having focused up to date on the response of fauna or flora communities in perennial crops, under different management systems (Bruggisser et al., 2010). Most of these were carried out in middle or high latitudes, but scarcely in the Mediterranean region, where climatic conditions are quite different (Ponce et al., 2011). Even further, only few studies have evaluated the effects of farming practices applied in olive production systems biodiversity (Cotes et al., 2009; Gonçalves and Pereira, 2012), while research focusing on functional subgroups of soil arthropods is scarce.

In this study, the soil arthropod community of olive orchards, located in southern Crete, Greece, was seasonally investigated over a period of two years, covering the full, biannual circle of olive production. The investigation included the monitoring of soil arthropod fauna in different management systems and agroecological zones. Furthermore, two "functional" sub-groups were defined, related to the prioritized agroecosystem services of biological pest control and nutrient cycling. Following an agroecological approach, climate conditions, farming practices and landscape factors were extensively monitored and correlated with the soil arthropod community in the olive agroecosystem.

The hypothesis of the study was that less intensified agricultural management generally supports greater taxa abundance and diversity. However, farming practices applied under commercial olive production and environmental factors are well expected to be important drivers shaping the soil arthropod community.

A general-to-specific approach was followed in order to:

(a) Compare soil arthropod community structure and diversity under different management systems (organic, conventional and integrated) and under different agroecological zones (hilly and plain).
(b) Investigate the correspondent response of the "functional" arthropods counterpart.
(c) Investigate the importance of factors related to environmental conditions, farming practices and landscape, with regards to their effect on soil arthropod community.

2. Materials and methods

2.1. Study sites and sampling periods

The survey took place in twenty four pilot orchards located in eight different locations in western Messara valley (35°01′N, 24°49′E), 40 km south of Heraklion, a representative olive production region in southern Crete, Greece. Each study location included three neighbouring orchards, one complying with organic standards according to European Union (EU) legislation (Council Regulation (EC) 834/2007), the second following an industry standard for integrated farming, according to the agri-environmental and sustainable development requirements of the EC 2078/92 and 1257/99, and the third complying with EU Common Agricultural Policy (CAP) framework describing conventional farming.

Orchards were managed commercially and had an average size of 0.53 ha, ranging from 0.17 to 1 ha, considered typical for the area (National Statistical Service of Greece, 2009) (Table 1). Orchards were selected following discussions with local stakeholders, and on the basis of previous research carried out in the area (Gkisakis et al., 2015; Kabourakis, 1999; Volakakis et al., 2012). The average distance between neighbouring orchards in each location was 150 m, and the minimum distance between locations was 1 km.

The study area's landscape consists mostly of olive orchards, covering both hilly and plain agroecological zones of olive production. These zones are differentiated upon elevation, terrain, abiotic (soil type and fertility, rainfall, temperature, humidity), and biotic environment (fauna and flora), and the intensity of management applied in the olive orchards; Cultivation in the hilly zone is considered less suitable for intensive farming practices and inputs, due the limitations posed by the terrain and the pedoclimatic conditions (Kabourakis, 1996; Metzidakis et al., 2008).

Information on the variety of practices applied in the different management systems was collected by means of standardized questionnaires, answered by the farmers participating to the survey. Weekly on-site observations were conducted during the two-year period of the study in order to monitor and quantify variables related to (i) soil management (proportion of orchard soil surface tilled), (ii) soil cover (proportion of orchard soil surface covered with vegetation), (iii) fertiliser applications (manure) and (iv) insecticide applications in the olive canopy, combating olive fly population (Table 1), as well as to validate the information provided by the farmers.

Climate data, including temperature and relative humidity were monitored and recorded hourly for each location, using HOBO data loggers (Onset Computer Corp., Bourne, MA) during the whole survey period. The data loggers were suspended in Stevenson screens as a standard weather shelter, following World Meteorological Organisation methodology (WMO, 1983).

Landscape complexity, defined as the proportion (%) of semi-natural habitats (SNH) surrounding the olive orchards, was measured in a radius of 200 m from the orchard centre, using official topographical maps and Quantum GIS 2.0.1 (QGIS) software (Quantum GIS Development Team, 2010). SNH included non-crop habitats like ditches, field margins, hedgerows, meadows and uncultivated grasslands. These elements are regarded as important for farmland biodiversity enhancement (Vollhardt et al., 2008). In our study area, the proportion of SNH among orchards ranged from 2.9 to 35.8% (Table 1).

The survey covered two standard production years (2011–2013), in terms of climatic conditions and considering the year-to-year deviation in olive tree yield (alternate bearing). The sampling period included five weeklong measurements for each season, from autumn 2011 to summer 2013 (winter: weeks 2–6; spring:

Table 1
Characteristics of pilot olive orchards, in terms of management systems, agroecological zones, farming practices (soil management, pesticide use and fertilization) and landscape complexity (seminatural habitats-SNH).

Site	Management system	Agroec. zone	Soil management				Pesticide use & fertilization				SNH (%)
			Tillage (%)		Soil cover (range%)		Insecticide (applications Nr)		Manure application		
			Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	
1	Organic	Hilly	100	70	10–90	10–80	x	x	Yes	Yes	9.3
	Conventional		90	90	20–100	10–90	2	3	x	x	35.8
	Integrated		0	0	90–100	70–85	2	3	x	Yes	8.3
2	Organic	Hilly	0	0	60–80	70–80	x	x	x	x	21.9
	Conventional		90	90	20–70	20–70	2	3	x	x	25.2
	Integrated		100	100	20–30	10–40	2	3	Yes	x	19.3
3	Organic	Plain	70	70	20–100	5–100	x	x	Yes	x	4.5
	Conventional		100	100	0–100	5–100	2	3	x	x	3.8
	Integrated		0	0	50–100	40–100	2	3	x	x	6.1
4	Organic	Plain	90	90	5–100	5–100	x	x	Yes	x	5.9
	Conventional		100	100	5–100	5–100	2	3	x	x	5.2
	Integrated		100	100	5–90	5–100	2	3	x	x	5.1
5	Organic	Plain	100	100	5–100	5–95	x	x	Yes	x	2.9
	Conventional		80	80	5–100	5–100	2	3	x	x	8.2
	Integrated		100	100	5–100	5–100	2	3	x	x	3.5
6	Organic	Hilly	70	0	40–100	30–90	x	x	x	Yes	9.7
	Conventional		100	100	5–70	5–100	2	3	x	Yes	22.9
	Integrated		90	100	10–90	5–80	2	3	x	Yes	21.2
7	Organic	Hilly	90	90	15–50	10–95	x	x	x	x	21.9
	Conventional		60	60	0–30	10–80	2	3	x	x	23.2
	Integrated		90	90	5–80	5–95	2	3	x	x	20.1
8	Organic	Plain	90	90	5–100	5–100	x	x	x	x	6.9
	Conventional		100	100	5–100	5–100	2	3	x	x	5.3
	Integrated		80	80	5–100	5–100	2	3	x	x	11.1

x: No application.

weeks 16–20; summer: weeks 27–31; autumn: weeks 42–46; for both 2011–2012 and 2012–2013), in total: 40 weekly measurements.

2.2. Soil arthropod monitoring

Six monitoring stations per hectare were defined for soil arthropod sampling; each one with a pitfall trap, with a minimum number of two traps per orchard. Half of the traps were placed under the olive tree canopy and the rest between olive trees in a random order. The average distance between traps was 20 m. Traps under canopy were placed on average 1.5 m from the olive tree trunk and 4 m when placed between trees. The traps were plastic, colourless, of 7.5 cm diameter and 11.5 cm height, filled with propylene glycol and were placed achieving minimum terrain disturbance. Each trap was left on site for a period of 7 days, considered appropriate for comparison purposes and based on previous research in the area (Kollaros et al., 2006). The samples collected were transported in plastic bags to the laboratory, filtered and cleaned of debris and inorganic material and examined by stereomicroscope (C-PS, Nikon).

Quantifiable morphological characteristics were followed for arthropod identification, up to the order level of taxonomy and to the level of class for Chilopoda and Diplopoda. Coleoptera were further classified at the family level for Scarabaeidae, Carabidae, Staphylinidae and Tenebrionidae, due to their importance for the agroecosystem services under study. Formicidae were counted separately from order Hymenoptera due to their abundance. Such higher level of arthropod taxonomisation, is considered to provide benefits for rapid biodiversity surveys (Cotes et al., 2010). It is mentioned as a particularly useful tool in the first phases of investigation for biodiversity assessments, comparing different land uses and agricultural management practices, when rapid results are required and financial resources are limited (Biaggini et al., 2007).

Chilopoda, Dermaptera and Diplopoda were not presented in tables due to scarcity (less than 1%). Diptera, Lepidoptera and Mecoptera, retrieved in pitfall traps, were not considered in the analysis, for not being true soil inhabitants.

In order to provide a representative image of the olive orchard “functional” fauna, the identified taxa were aggregated in two subgroups, according to the functions provided by the majority of their species, as related to the target services of biological pest control (BPC) and decomposition-nutrient cycling (NC). BPC subgroup was formatted by arthropod taxa which majorly include typical potential predators of the Tephritidae pupae such as Araneae, Carabidae, Staphylinidae, Formicidae and Opiliones (Gonçalves and Pereira, 2012; Urbaneja et al., 2006). NC subgroup included taxa where main decomposers and detritivores are encountered, including Scarabeidae, Tenebrionidae, Acari, Collembolla, Isopoda and Thysanura (Stork and Eggleton, 1992; Wurst, 2013).

2.3. Data analysis

Arthropod community in different management systems and agroecological zones was described in each season, accumulatively for the two years period, in terms of (a) relative abundance of each

Table 2
Relative abundance of soil arthropod taxa per hectare, abundance of total arthropod catches and functional subgroup, relative abundance of functional subgroups (BPC: Biological Pest Control group, NC: Nutrient Cycling group), values of richness and biodiversity indexes for the organic (Org), conventional (Conv) and integrated (Int) management systems and hilly and plain agroecological zones.

	Autumn					Winter					Spring					Summer				
System/zone	Org	Conv	Int	Hilly	Plain	Org	Conv	Int	Hilly	Plain	Org	Conv	Int	Hilly	Plain	Org	Conv	Int	Hilly	Plain
Taxa																				
Acari	3.6	3.1	3.1	3.2	3.3	1.7	1.1	1.8	1.5	1.5	6.2	3.0	2.1	5.2	2.6	4.6	4.4	1.6	2.9	4.4
Araneae	14.0	14.7	15.2	12.7	16.8*	20.6	18.6	22.4	14.6	25.5*	6.1	5.3	6.1	7.0	4.7	7.2	7.6	9.6	8.8	7.3
Coleoptera	19.9	19.0	18.4	14.6	24.4*	10.0	10.8	11.6	12.7**	9.4	52.1	55.6	53.2	45.9	61.2**	18.2	30.6	26.6	22.6	26.2
Scarabaeidae	4.6	1.8	1.1	4.5**	0.4	0.4	0.5	0.4	1.0**	0.0	3.5	2.0	1.7	4.2**	0.7	0.0	0.1	0.2	0.2**	0.0
Carabidae	5.7	6.8	6.0	3.9	8.7**	1.5	1.6	1.7	1.6	1.7	1.9	2.3	1.5	1.0	2.8**	0.1	0.3	0.3	0.1	0.3*
Staphylinidae	4.6	3.7	5.0	3.0	6.1*	3.7	5.1	4.4	4.9	3.9	3.2	4.2	4.3	3.2	4.5	0.1	0.0	0.1	0.1	0.1
Tenebrionidae	0.8	0.7	0.5	0.3	1.0*	0.7	0.2	0.5	0.2	0.6	29.9	31.1	30.2	25.2	35.6*	7.4	9.2	7.4	10.9	5.2
other	4.3	6.1	5.8	2.8	8.2	3.7	3.4	4.6	4.9*	3.2	13.4	16.0	15.5	12.2	17.6	10.6	21.0	18.7	11.4	20.6*
Collembola	10.4	21.2	13.0	17.1	12.0	33.5	39.6	35.1	31.9	39.5	2.3	1.4	2.5	2.1	2.0	2.0	3.3	2.0	3.7	1.2
Dictyoptera	0.6	0.3	0.3	0.6	0.3	0.4	0.0	0.3	0.3	0.1	0.4	0.8	0.3	0.3	0.7	8.9	9.2	10.2	4.9	13.6*
Formicidae	28.4	23.1	26.1	25.9	26.0	2.6	3.8	3.2	3.3	3.2	21.6	21.1	20.6	24.1*	18.1	53.7	36.1	41.3	50.1*	39.6
Hemipt./Heteropt.	0.1	0.2	0.1	0.2	0.1	0.1	0.2	0.4	0.4	0.2	0.3	0.4	0.3	0.5**	0.1	0.2	2.7	0.8	2.2	0.1
Other Hemiptera	0.6	0.5	1.2	0.9	0.6	1.6	1.7	1.8	2.3**	1.3	1.4	1.2	1.6	2.0**	0.8	0.7	0.6	1.0	0.9	0.7
Hymenoptera	0.5	0.6	0.5	0.5	0.6	0.3	0.1	0.1	0.2	0.2	0.5	0.5	0.6	0.8**	0.2	1.1	1.0	1.0	0.8	1.3
Isopoda	5.6	6.5	7.8	5.4	7.9	1.7	1.2	1.7	1.7	1.5	3.1	4.8	6.8	3.1	6.5**	2.2	2.4	3.7	2.3	3.1
Opiliones	14.7	7.6	10.5	16.7*	4.6	24.9	19.6	20.2	29.3*	15.2	5.3	4.4	4.9	7.8**	2.0	0.0	0.0	0.0	0.0	0.0
Orthoptera	0.7	0.6	1.1	0.6	1.0	0.5	0.4	0.6	0.3	0.7	0.3	0.6	0.4	0.3	0.4	0.6	1.4	1.6	0.4	1.8*
Thysanura	0.3	1.2	0.5	0.7	0.6	0.2	0.5	0.4	0.4	0.4	0.1	0.1	0.1	0.2*	0.0	0.1	0.1	0.0	0.1	0.1
Total abundance	9,418	8,506	8,212	13,930	12,205	5,097	5,362	5,923	7,323	9,059	40,317	32,205	34,511	53,762	53,271	29,165	22,401	20,232	35,084	36,714
Functional taxa	8,725	7,681	7,300	5,198	4,338	4,668	4,924	5,434	2,785	2,874	33,593	25,652	27,853	44,666	42,432	22,578	14,223	13,411	27,747	22,465
BPC	67.3	55.9	62.9	62.2	62.3	53.4	48.7	51.8	53.6	49.5	38.1	37.4	37.3	43.1**	32.1	61.1	44.0	51.3	59.1*	47.2
NC	27.3	38.1	29.2	83.8	71.1	41.7	46.9	43.5	96.6	136.9	54.3	53.0	53.8	48.1	59.7*	21.1	30.7	22.6	25.3	22.8
S	15	15	15	15	15	16	14	15	16	15	15	16	16	16	16	16	14	14	15	16
1-D	0.744	0.738	0.732	0.726	0.751	0.708	0.665	0.665	0.686	0.672	0.600	0.610	0.604	0.657**	0.552	0.656	0.695	0.666	0.633	0.713*
J	0.764	0.818	0.789	0.789	0.792	0.746	0.792	0.780	0.786	0.760	0.551	0.614	0.584	0.634**	0.532	0.630	0.723	0.690	0.659	0.704

S: Richness of orders & classes. 1-D: reverse Simpson's Index. J: Pielou's evenness Index. Other taxa counted and not presented due to scarcity (<1%): Chilopoda. Dermaptera. Diplopoda, * $p < 0.05$, **$p < 0.01$.

taxon, represented by the ratio between its abundance and the total catches per orchard surface, (b) abundance of total catches and functional taxa, per management system and agroecological zone (c) relative abundance of BPC and NC functional subgroups, as the proportion of sum of abundances of the taxa belonging to each group, to the total arthropod abundance, (d) species richness (S), (e) reverse Simpson's Index of diversity (1-D), as a main robust and meaningful diversity index (Magurran, 2004) and (f) the Pielou Index (J), representing community evenness.

A step-wise data analysis was performed, starting from the comparison of relative taxa abundance, total catches, functional subgroups and biodiversity indexes, between managements systems and between agroecological zones, by univariate statistical analyses, using SPSS 20.0 for Windows. Data assessed for normality by Shapiro–Wilk test ($p < 0.05$) were found to be not normally distributed, even after several transformation types. Therefore, a non-parametric Kruskall–Wallis test was run to determine whether differences occurred between management systems and Mann–Whitney test for differences between agroecological zones. Significance was reported at the level of $p < 0.05$.

Multivariate analyses were carried out thereafter, using CANOCO 5 software (Šmilauer and Lepš, 2014) performed on data of each season. A set of explanatory variables of main interest was set weekly over the two years, including climate data of average air temperature and relative humidity, soil management status expressed by proportion (%) of soil tillage, proportion (%) of soil cover, application or not of manure, number of annual insecticide applications and landscape complexity status, expressed by semi-natural habitats proportion. Management systems and agroecological zones were also grouped and partial out as covariates, in order to focus on the influence of the first group of main interest.

Ordination method of Detrended Correspondence Analysis (DCA) was initially used to select the most adequate response model to follow; either linear or unimodal (ter Braak and Šmilauer, 2002). Detrending was done by segments and species data were log transformed ($\log(y+1)$). Based on the gradient length of first axis, Redundancy analysis (RDA) was chosen (ter Braak and Šmilauer, 2002). Scaling on inter-species correlations was used and species scores were divided by standard deviation. The level of significance in the analysis was assessed by Monte-Carlo test (499 random permutations).

Variation partitioning analyses were performed in order to distinguish the relative contributions of the two different groups of variables to explanation of the soil arthropod community composition. The estimated fractions of explained variation were based on the estimates based on the "adjusted coefficient of

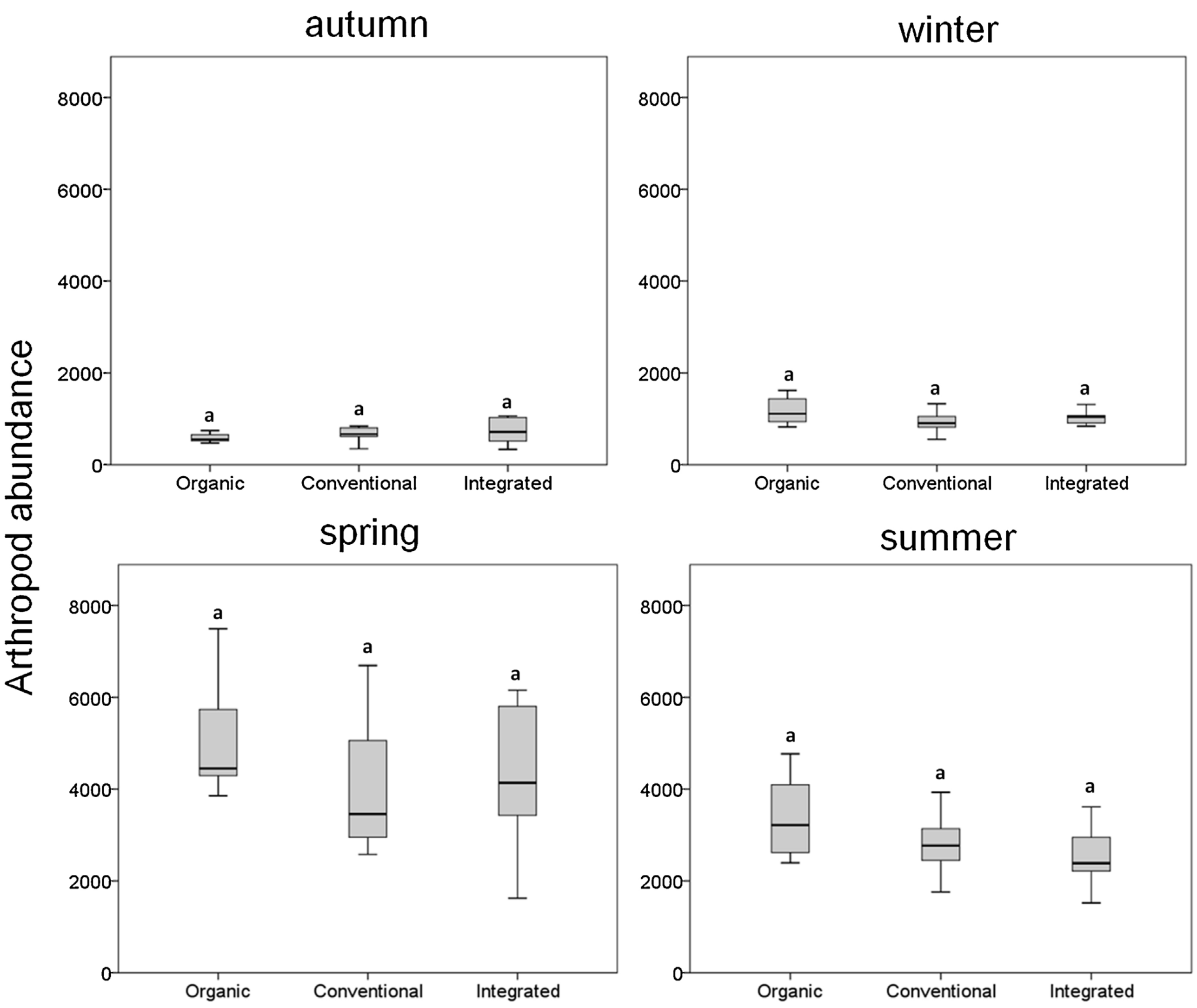

Fig. 1. Boxplots of soil arthropod abundance in different management systems, presenting medians and quartiles, accumulative for the period 2011–2013. Significant differences are indicated by lowercase letters.

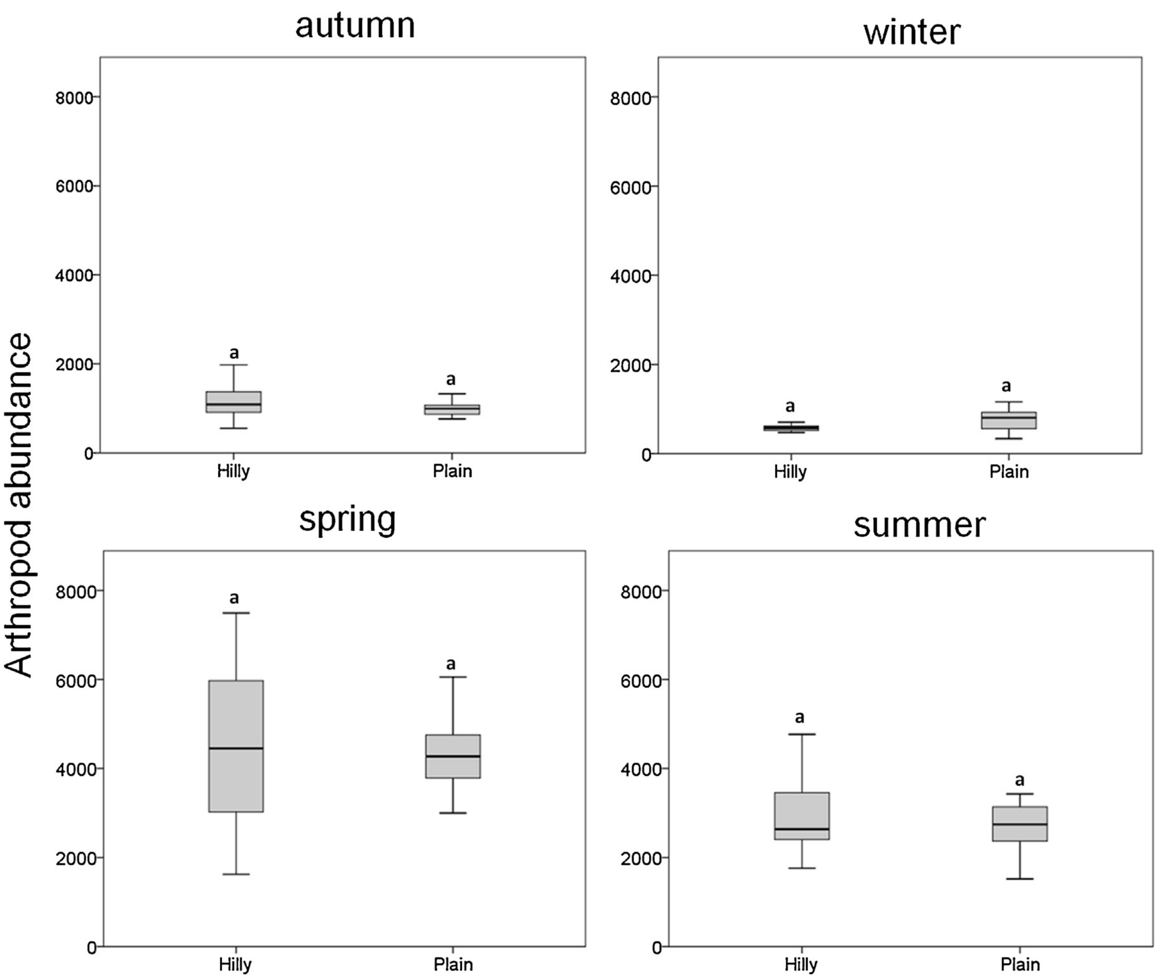

Fig. 2. Boxplots of soil arthropod abundance in different agroecological zones, presenting medians and quartiles, accumulative for the period 2011–2013. Significant differences are indicated by lowercase letters.

determination" (R^2adj) approach (Peres-Neto et al., 2006). In order to analyze the relative importance of each group of explanatory variables the proportion of their total variability explained was used and not their absolute impact, following Økland (1999) and Schweiger et al. (2005). Stepwise analyses through forward selection was used to test the significance and strength of the explanatory variables for each variable group, holding each time one of them constant, as covariates. Location and survey year were in all cases held constant as covariates, in order to display the patterns of species data uniquely attributed to the above two

Table 3

Results of RDA and forward selection, including the % explanatory contribution of the two groups of variables at the moment of its selection, related to the total, the % of cumulative variation explained by the first/second axis and values of *F*: F-ratio and *P*: adjusted value of significance level, following Bonferroni correction, obtained by Monte Carlo test, 499 permutations ($^*p < 0.05$). Values of variables with no contribution (n.c.) to the total variation are not shown.

Variables	Autumn			Winter			Spring			Summer		
	Explains%	*F*	*p* (adj)	Explains%	*F*	*p* (adj)	Explains%	*F*	*p* (adj)	Explains%	*F*	*p* (adj)
Temperature	7.1	17.7	0.01*	1.6	3.7	0.012*	5.4	13.3	0.012*	n.c.		
Relative humidity	0.4	1.0	1.00	1.0	2.4	0.048*	3.3	8.7	0.012*	1.3	3.3	0.036*
Soil tillage	1.4	3.6	0.01*	1.1	2.6	0.084	3.6	9.1	0.012*	3.4	8.2	0.012*
Soil Cover	0.9	2.3	0.07	1.1	2.6	0.048*	1.0	2.7	0.048*	n.c.		
Manure	1.0	2.6	0.04*	0.8	2.0	0.3	1.3	3.4	0.012*	1.5	3.7	0.012*
Landscape complexity	1.0	2.6	0.04*	1.0	2.4	0.144	1.3	3.5	0.012*	2.7	6.5	0.012*
% Axis 1	7.6			2.3			9.1			5.0		
% Axis 2	1.7			1.6			3.7			2.1		
Total variation expl. (%)	11.8			6.5			17.8			8.8		
Organic	1.9	4.6	0.02*	1.3	3.1	0.02*	2.7	6.5	0.01*	n.c.		
Conventional	0.6	1.5	0.76	0.4	1.0	1.00	n.c.			n.c.		
Integrated	n.c.			n.c.			0.5	1.2	1.	1.7	4.3	0.01*
Agroecological zone	2.7	6.5	0.01*	2.2	5.1	0.018*	3.5	8.4	0.01*	6.2	15.2	0.01*
% Axis 1	3.9			1.6			4.5			6.2		
% Axis 2	0.8			1.1			2.2			1.7		
Total variation expl. (%)	5.2			2.8			6.7			7.9		

groups. Adjustment of p-values was used, following the Bonferroni correction method against Type I error inflation. The stopping criteria of (a) alpha significance and (b) the adjusted coefficient of multiple determination (R^2a), calculated using all explanatory variables were applied, following Blanchet et al. (2008).

The variance inflation factors (VIF) of each variable was identified during preliminary analyses, measuring how much of the variance of the canonical coefficients is inflated by the presence of correlations among explanatory variables. The rule of $VIF < 20$ was applied as defined by ter Braak and Šmilauer (1998) and no significant correlations were found among explanatory variables, as VIF had in most cases a value of approx. 1.5.

Biplots of t-values were constructed from RDA for each one of the explanatory variables contributing to the explanation of arthropod variability using the Van Dobben method (ter Braak and Looman, 1994). Under this approach, the taxa vectors (band types) enclosed in the Van Dobben circles indicate the significance of their relationships (t-value $< |2|$) with the explanatory variables.

Principal Component Analysis (PCA) was finally used to generate a taxa-variable biplot diagram which provides predictions on their relationship, without constraining the ordination axes to be linear combination of the explanatory variables, by displaying the maximum variation in the data (Moonen and Marshall, 2001).

3. Results

3.1. Total arthropod abundance

A total of 221,348 arthropods were captured, classified into 16 taxa (orders and classes), as well as another four Coleopteran families, found in all management systems and agroecological zones. The highest catches appeared in spring's sampling period, followed by summer, autumn and winter.

Values of arthropod catches fluctuated among olive orchards, but the differences of abundance were not statistically significant, neither between management systems nor between agroecological zones, in all sampling seasons. (Table 2, Appendix A and Appendix B present the results of the statistical tests and Figs. 1 and 2 present the correspondent visual representation of seasonal abundance's medians and quartiles). The same accounted for Simpson's and Pielou's evenness index in the management systems comparison. For agroecological zones, hilly orchards presented significantly higher values for both indexes in spring and plain orchards presented a higher Simpson's index in summer (Table 2 and Appendix B).

3.2. Functional arthropods

176,041 arthropods were defined as "functional", representing 79.5% of the total arthropods caught, throughout the study period (Table 2). A proportion of 58.5% was aggregated in the BPC subgroup of functional taxa, while the rest 41.5% in the NC group.

Statistical differences of functional arthropods between management systems and between agroecological zones were not significant in any of the seasons. (Table 2, Appendix A and Appendix B). The BPC subgroup however, presented significantly higher values of relative abundance in hilly orchards, in spring and summer, and NC was higher in the plains, in spring (Table 2 and Appendix B).

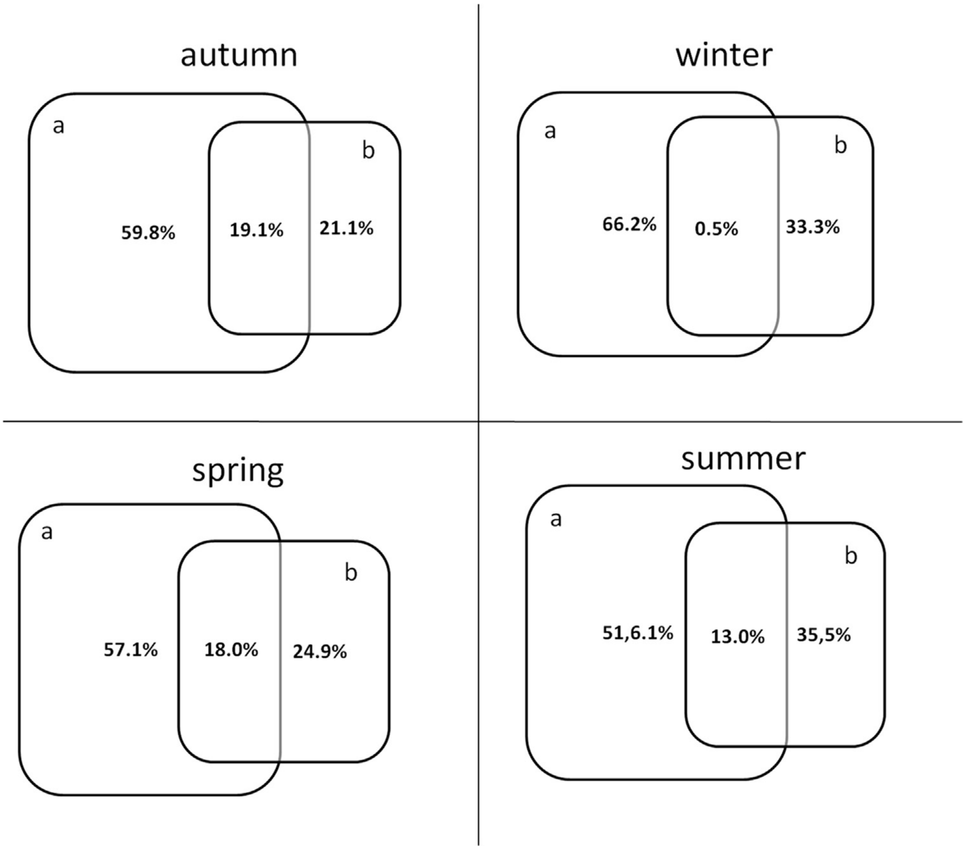

Fig. 3. Variation partitioning Venn diagrams representing the unadjusted percentages of variance explained of soil arthropod.
Fraction (a) represents the variability explained by the variables set of temperature, relative humidity, soil tillage, soil cover, landscape complexity and manure, while (b) represents the variability explained by the set of management systems and agroecological zones, ($p < 0.01$).

Table 4
Relationship between soil arthropod taxa and explanatory variables (t-value < |2|), based on the regression coefficient of multiple regressions between arthropods and variables, delivered by the t-value biplots (RDA).

Taxa-variables relationship	Positive				Negative			
	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer
Acari	T						RH, Till	
Araneae	T	RH			Till		T, RH, Till	
Coleoptera	T, Mn			Till		T	T, RH	
Scarabeidae	T			SNH				
Carabidae	T							
Staphylinidae	T						T, RH, Cov, Mn	
Tenebrionidae	T		Till	Till			T, RH	
Other							T, RH, Mn	
Collembola	T	RH		Till			T	
Dictyoptera				SNH				
Formicidae	T	Cov					Till	Till, Mn
Hemipt./Heteropt.	T						T, RH	
Other Hemiptera	T						Till	Mn
Hymenoptera				Till			T	
Isopoda	T		T			T	Till	Till
Opiliones					Mn		T	
Orthoptera	T		T					
Thysanura	T							

Explanatory variables abbreviations: T: average temperature, RH: relative humidity, Till: soil tillage, Cov: soil cover, SNH: landscape complexity, Mn: manure application.

3.3. Specific taxa

The most dominant taxa in the whole sampling period were Coleoptera, accounting for 39.52% of the total catches, followed by Formicidae (28.02%), Araneae (8.69%) and Collembola (6.20%). Among Coleopterans, Tenebrionidae was the most abundant family, reaching 47.15% of the order's total catches. None of the specific taxa's relative abundance showed statistical differences between management systems (Table 1 and Appendix A). On the other hand, agroecological zones presented differences for seven taxa in autumn (two taxa higher in hilly orchards and five in the plain ones), six taxa in winter (five taxa higher in hilly and one in the plains), five taxa in summer (two taxa higher in hilly, three in the plain), while the highest number of significant differences were found in spring, with seven taxa higher in hilly and three in plain orchards (Table 2 and Appendix B).

3.4. Multivariate analysis

Preliminary forward selection analyses gave that insecticide applications did not contribute to the explanation of variability in any of the sampling periods and it was excluded from the generated ordination model. In the partial RDA analyses followed, the variation explained by the 1st group, including climate, farming practices and landscape factors accounted from 6.5% in winter to 17.8% in spring (Table 3), after removing the effect of covariates. The group of management systems and agroecological zone instead, explained total variation from 2.8% in autumn to 7.9% in summer. In addition, variation partitioning, determining the unique and joint fractions of variation explained, gave that the 1st group of factors explained always a larger proportion of total variability ranging from a minimum 51.6% in summer to a maximum 66.2% in winter (Fig. 3). Group of managements systems and agroecological zones on the other hand, explained always a smaller proportion ranging from 21.1% in autumn to 35.5% in summer.

Among variables, temperature explained most of the variation of arthropod community in autumn, winter and spring (Table 3). This was confirmed by the *t*-values biplots and Van Dobben method, appearing to have a significant positive correlation with fourteen taxa in autumn, negatively with two taxa in winter and eleven in spring (two positively and nine negatively) (Table 4). The post-hoc projection of temperature on the PCA ordination space (Fig. 4) predicted most of the correlations species community, while it appeared positively correlated with the 1st axis in autumn and spring, and the 2nd axis in summer.

Relative humidity explained significantly the species variation in winter and spring, ranking 3rd in terms of variation explained, as well as 4th in summer (Table 3). It had a significantly positive correlation with two taxa in winter and it was negatively correlated with seven taxa in spring (Table 4). In the PCA biplot appeared positively correlated with the 1st ordination axis in autumn and summer, while it was negatively correlated with the 2nd axis in spring.

Soil tillage proportion presented a high explanation rate in autumn and spring, ranking 2nd in both periods, while it explained most of the total variation among all variables in summer (Table 3). It presented a significantly negative correlation with one taxa in autumn, six taxa in spring, one of them positively, and with six taxa in summer (two negatively and four positively). A positive correlation appeared with the 1st ordination axis in spring and with the 2nd in summer. On the other hand, proportion of soil cover ranked 2nd in winter and only last in spring and it had a significant positive correlation with one taxon in winter and negative with another one in spring. In the PCA ordination space positive correlation appeared with the 1st axis in spring and the 2nd in winter. The above two variables were projected lying in relatively opposite directions or presented a large Euclidean distance among them, in the species-variables biplots (Fig. 4).

Landscape complexity provided significant explanation in autumn (3rd), spring (4th) and summer, ranking 2nd (Table 3). It had a significant positive effect only on two taxa in summer (Table 4) and presented a negative correlation with the 1st ordination axis in autumn and summer.

Finally, manure application provided a rather average explanation ranking 4th in autumn, 5th in spring and 3rd in summer. A significant correlation appeared with two taxa in autumn, one of them negatively, and a negative relation with two taxa in summer. A correlation with the 2nd axis was apparent in autumn (positive), as well as in winter and spring (negative).

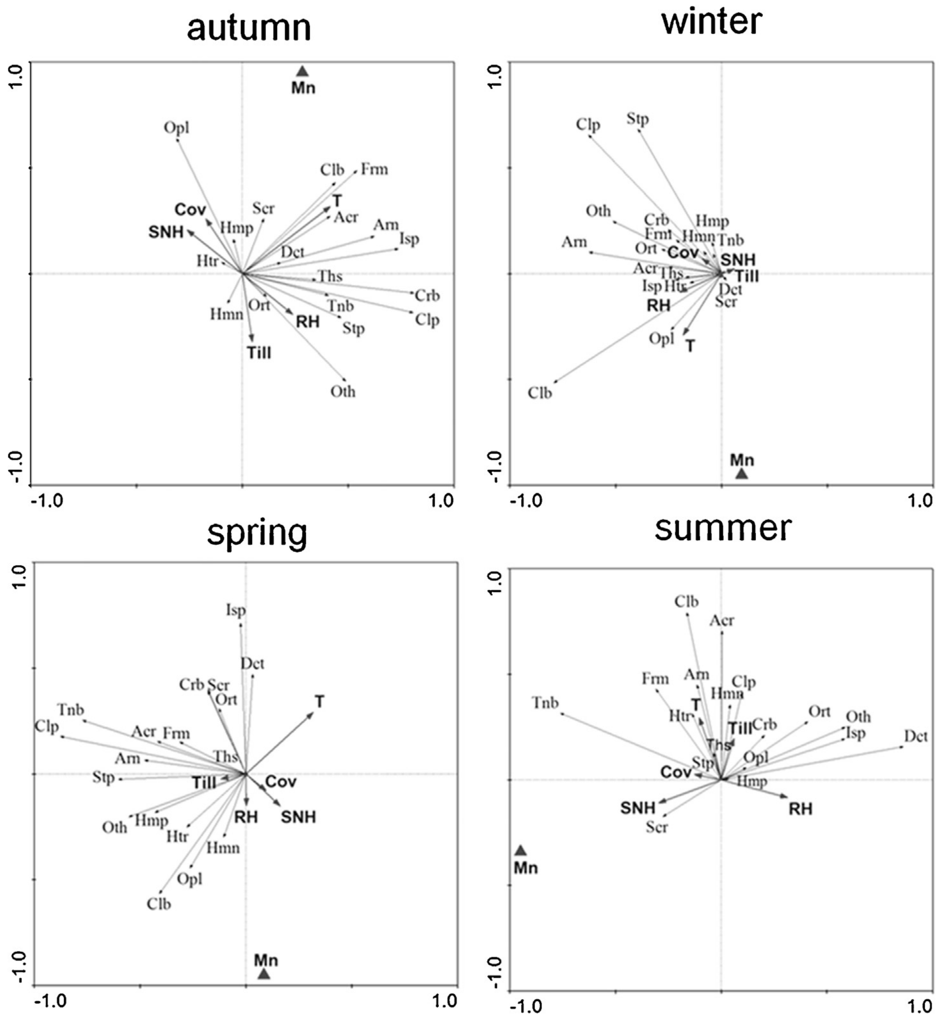

Fig. 4. PCA of soil arthropod taxa as response variables and explanatory variables of the four study periods (autumn, winter, spring, summer). Explanatory variables are post-hoc projected on the ordination space. Least abundant taxa and variables which do not contribute to explanation of variability do not appear.
Taxa abbreviations: Acari: Acr; Aranae: Arn; Coleoptera: Clp; Scarabaeidae: Scr; Carabidae; Crb; Staphylinidae: Stp; Tenebrionidae: Tnb; Other Coleoptera: Oth; Collembola: Clb; Dictyoptera: Dct; Formicidae: Frm; Heteroptera: Htr; Other Hemiptera: Hmp; Hymenoptera: Hmn; Isopoda: Isp; Opiliones: Opl; Orthoptera: Ort; Thysanura: Ths.
Explanatory variables abbreviations: T: average temperature, RH: relative humidity, Till: Soil tillage, Cov: soil cover, SNH: Landscape complexity, Mn: manure application.

4. Discussion

The results of arthropod assemblages were comparable with previous studies in terms of most abundant taxa and peak season. However, comparison of the abundance and diversity provided significant differences only in terms of agroecological zones, and not management systems, unlike other studies. Furthermore, abiotic, management and landscape factors provided better explanation than management systems and agreocological zones did. Specifically, the peak season of soil arthropod assemblage was comparable with the findings of Cotes et al. (2010) and Ruano et al. (2004), who determined the end of spring and early summer as those with the highest numbers of different soil arthropods. The four most dominant taxa found to compose the soil arthropod community, Coleoptera, Formicidae, Araneae and Collembola, are also reported in previous similar studies as the most abundant in the olive agroecosystems (Cotes et al., 2010; Jerez-Valle et al., 2014; Morris and Campos, 1999; Ruano et al., 2004; Santos et al., 2007).

Non-significant differences of the arthropod abundance and diversity indexes between management systems did not consist with similar studies (Ruano et al., 2004; Cotes et al., 2010), who presented increased number of arthropods in the organic orchards. According to Hole et al. (2005) and Bengtsson et al. (2005) such non-discriminating results could be attributed to reasons of heterogeneity of agricultural practices applied within the same management system, as well as to climate parameters and to different response of species to management disturbance. Both relative abundance and “functional” subgroups presented a similar ranking and fluctuation among management systems in all seasons, as expected due to the high proportion of arthropod catches comprising the functional subgroups.

Despite the non-significant differences of neither relative abundance nor the “functional” counterpart, a remarkable differentiated response to agroecological zone of several specific functional taxa appeared in all seasons, including BPC subgroup in spring and summer and NC in spring. This could be attributed to the significantly different catches of taxa, such as Formicidae and Opiliones, among hilly and plain orchards.

Ordination analyses demonstrated that the group of climate, soil management and landscape factors provided a better explanation on arthropod variability, comparing to the management systems and agroecological zones together. The variability unexplained by both these group of factors was rather high, without meaning that the generated model and ordination diagrams cannot be interpreted ecologically (Økland, 1999). It is also mentioned in the literature that a well interpretable structure can be delivered even if the amount of variability explained is less than 10% (ter Braak and Šmilauer, 2002).

In the taxa-variables relationship test of significance, temperature proved to be a major abiotic factor, explaining the variability of arthropod community and of a large number of specific taxa. Arthropods as ectotherms, respond strongly to temperature, which besides of being an important factor influencing their development rate (Briere et al., 1999), also changes the activity levels and alters an arthropod's probability of capture by a pitfall trap (Southwood, 1966). In addition, McIntyre et al. (2001) described that arthropod richness and abundance correspond more closely to air temperature, possibly because the latest can be monitored with a greater degree of accuracy, eventually shaping a much more robust variable.

Not surprisingly, soil tillage also influenced highly the arthropods variation, especially in summer and spring, where the tillage effect is mostly expressed. Soil disturbance stands among the practices causing physical damage or death to many detritivorous and predatory arthropods (Wardle, 1995), changes food availability (Sharley et al., 2008) and alters soil conditions, with a significant effect on arthropods, such as soil pores and microclimate (Grandy and Robertson, 2006). Different response of specific taxa to tillage was obvious, with Formicidae, Araneae and Acari having a predictable negative response (Shrestha and Parajulee, 2010; Ward et al., 2011). Positive response to tillage of Coleoptera, specifically Tenebrionidae, would not be expected following literature (Sharley et al., 2008), while the positive response of Collembola, have been shown in previous studies (De Ruiter et al., 1975). Generally, the response of microarthropods to management intensity is referenced as less consistent, most likely due to small body size, high variability in dispersal potential, generation time, dormancy capacity, and fecundity (Wardle, 1995; Wickings and Grandy, 2013). Furthermore, Mackey and Currie (2001) state that the location of the diversity maxima in different taxa, within the framework of Intensity Disturbance Hypothesis (IDH), may not be at the same position along the disturbance gradient.

Relative humidity had an average effect on soil arthropods, and besides the expected positive response of Collembola to moisture in winter (Setälä et al., 1995), a positive response of Araneae and several Coleopteran families would be expected. A greater response to the factor of soil cover was also expected since it provides microhabitat by delivering food sources, moderating the effects of extreme soil temperatures and also reduces moisture loss rates from the soil surface (Coleman et al., 2002). Increasing landscape complexity provided a fair contribution to the regression model generated, when compared with climate and soil management factors, even if it is assessed as pervasive and sometimes more important than the farming practices applied (Aavik and Liira, 2010; Gardiner et al., 2009).

Manure application contributed less than all factors to the explanation of variability, although a stronger response is cited (Weil & Kroontje, 1979) as among the multiple benefits it provides, is the benefit of allowing omnivores and predaceous species to increase their presence (Neher, 1999).

Finally, the non-contribution of insecticide application to soil arthropod variability explanation could be attributed to its target use on olive tree canopy, even if it appears as a contributing factor in a previous similar study (Cotes et al., 2010).

5. Conclusions

The study provided significant data on the soil arthropod community of the perennial olive orchard agroecosystem and its relationship with management and agroecological factors. It was expected that management systems, characterised by different levels of intensification, would deliver a pronounced effect on soil arthropod diversity and abundance; however, climate factors, like temperature as well as relative humidity, and specific farming practices, especially soil tillage intensity, proved to be much more important drivers shaping it.

The seasonal highlighted response of soil arthropod diversity, relative taxa abundance and functional subgroups providing biological pest control and nutrient cycling services, indicated a more discriminating effect of the agroecological zone of cultivation than the management system applied.

The sole consideration of management systems followed for explaining the variability of soil arthropods in the olive agroecosystem appeared as a least robust approach. Environmental and agricultural management factors should therefore be regularly reconsidered when the impact on biodiversity of olive agroecosystem is assessed.

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Appendix A. Results of the Kruskal–Wallis test between management systems

Results the Kruskal–Wallis test applied for the comparison of the accumulative relative abundance of soil arthropod taxa per hectare, the abundance of total arthropod catches and functional subgroup and the relative abundance of functional subgroups (BPC: Biological Pest Control group, NC: Nutrient Cycling group), values of richness and biodiversity indexes between management systems, for the study period 2011–2013.

Taxon	Autumn $\chi 2(p)$	Winter $\chi 2(p)$	Spring $\chi 2(p)$	Summer $\chi 2(p)$
Acari	0.37	4.53	4.32	2.16
Araneae	0.73	0.64	0.13	2.34
Coleoptera	0.15	0.54	0.14	3.35
Scarabaeidae	0.53	0.10	0.32	0.57
Carabidae	0.72	0.02	1.94	1.17
Staphylinidae	0.85	2.91	2.54	1.96
Tenebrionidae	1.23	1.42	0.24	0.45
Other	1.23	2.64	0.85	3.84
Collembola	0.38	2.44	3.54	1.05
Dictyoptera	0.66	2.28	2.36	1.22
Formicidae	1.67	1.04	0.02	2.20
Heteroptera	0.13	0.49	0.27	1.70
Other Hemiptera	3.22	0.07	0.55	0.73
Hymenoptera	0.05	3.88	0.04	0.52
Isopoda	0.98	3.88	0.04	0.52
Opiliones	2.78	1.69	0.17	2.29
Orthoptera	1.33	0.32	1.74	0.38
Thysanura	4.60	2.59	0.82	1.31
Measures				
Total abundance	1.04	1.24	3.35	1.07
Functional taxa	0.85	1.24	3.01	3.56
BPC	2.94	2.89	0.09	2.10
NC	1.36	2.35	0.62	1.08
1-D	0.27	3.62	0.13	1.13
J	1.75	1.51	1.75	5.36

1-D: reverse Simpson's Index, J: Pielou's evenness Index.

Appendix B. Results of the Mann–Whitney test between agroecological zones

Results the Mann–Whitney test applied for the comparison of the accumulative relative abundance of soil arthropod taxa per hectare, the abundance of total arthropod catches and functional subgroup and the relative abundance of functional subgroups (BPC: Biological Pest Control group, NC: Nutrient Cycling group), values of richness and biodiversity indexes between agroecological zones, for the study period 2011–2013.

Taxon	Autumn		Winter		Spring		Summer	
	U	*Z*	*U*	*Z*	*U*	*Z*	*U*	*Z*
Acari	73.0	0.058	72.0	0.000	49.0	−1.328	83.0	0.635
Araneae	109.0*	2.136	116.0*	2.540	40.0	−1.848	63.0	−0.520
Coleoptera	111.0*	2.252	24.0**	−2.77	119.0**	2.710	85.0	0.751
Scarabaeidae	20.5**	−2.99	24.0**	−3.307	16.0**	−3.233	29.0**	−2.678
Carabidae	127.0**	3.176	89.5	1.011	129.0**	3.292	109.0*	2.163
Staphylinidae	115.0*	2.483	61.0	−0.635	92.0	1.155	75.5	0.208
Tenebrionidae	110.5*	2.234	97.5	1.529	109.0*	2.136	38.0	−1.963
Other	105.0	1.905	36.0*	−2.079	96.0	1.386	107.0*	2.021
Collembola	77.0	0.289	105.0	1.905	69.0	−0.173	54.0	−1.039
Dictyoptera	75.0	0.199	60.5	−1.022	93.5	1.242	116.0**	2.540
Formicidae	59.0	−0.751	75.0	0.173	37.0*	−2.021	30.0*	−2.425
Heteroptera	52.0	−1.215	58.5	−0.929	13.5**	−3.383	45.5	−1.942
Other Hemiptera	60.5	−0.664	67.6**	−2.570	14.0**	−3.349	69.0	−0.173
Hymenoptera	81.0	0.520	73.5	0.100	12.5**	−3.437	104.0	1.849
Isopoda	91.5	1.129	73.5	0.100	12.5**	−3.437	104.0	1.849
Opiliones	20.0**	−3.002	29.0**	−2.483	2.5**	−4.013	83.5	1.022
Orthoptera	83.4	0.666	91.5	1.227	81.5	0.549	111.0*	2.253
Thysanura	65.0	−0.407	73.5	0.087	29.5*	−2.481	77.0	0.309
Measures								
Total abundance	56.0	−0.924	102.0	1.732	70.0	−0.115	71.0	−0.058
Functional taxa	46.0	−1.501	103.0	1.791	68.0	−0.231	40.0	−1.848
BPC	65.0	−0.404	56.5	−0.895	22.00**	−2.897	30.0*	−2.425
NC	63.0	−0.520	97.0	1.443	107.0*	2.021	47.0	−1.443
1-D	102.5	1.761	54.0	−1.039	16.0**	−3.234	109.5*	2.166
J	71.5	−0.029	60.5	−0.664	26.0**	−2.656	84.0	0.693

$^{*}p < 0.05$, $^{**}p < 0.01$.

References

Aavik, T., Liira, J., 2010. Quantifying the effect of organic farming, field boundary type and landscape structure on the vegetation of field boundaries. Agric. Ecosyst. Environ. 135, 178–186.

Altieri, M., 1999. The ecological role of biodiversity in agroecosystems. Agric. Ecosyst. Environ. 74, 19–31.

Bàrberi, P., 2013. Functional agrobiodiversity: the key to sustainability? In: Gurbir Bhullar, S., Navreet Bhullar, K. (Eds.), Agricultural Sustainability-Progress and Prospects in Crop Research. Elsevier, London, Waltham, San Diego, pp. 3–20.

Bengtsson, J., Ahnström, J., Weibull, A.C., 2005. The effects of organic agriculture on biodiversity and abundance: a meta-analysis. J. Appl. Ecol. 42, 261–269.

Biaggini, M., Consorti, R., Dapporto, L., Dellacasa, M., Paggetti, E., Corti, C., 2007. The taxonomic level order as a possible tool for rapid assessment of Arthropod diversity in agricultural landscapes. Agric. Ecosyst. Environ. 122, 183–191.

Blanchet, F.G., Legendre, P., Borcard, D., 2008. Forward selection of explanatory variables. Ecology 89, 2623–2632.

Briere, J.F., Pracros, P., Le Roux, A.Y., Pierre, J.S., 1999. A novel rate model of temperature-dependent development for arthropods. Environ. Entomol. 28, 22–29.

Bruggisser, O.T., Schmidt-Entling, M.H., Bacher, S., 2010. Effects of vineyard management on biodiversity at three trophic levels. Biol. Conserv. 143 (6), 1521–1528.

Coleman, D., Fu, S., Hendrix, P., Crossley Jr., D., 2002. Soil food webs in agroecosystems: impacts of herbivory and tillage management. Eur. J. Soil Biol. 38, 21–28.

Cotes, B., Castro, J., Cardenas, M., Campos, M., 2009. Responses of epigeal beetles to the removal of weed cover crops in organic olive orchards. Bull. Insectol. 62, 47–52.

Cotes, B., Campos, M., Pascual, F., García, P.A., Ruano, F., 2010. Comparing taxonomic levels of epigeal insects under different farming systems in Andalusian olive agroecosystems. Appl. Soil Ecol. 44, 228–236.

Daane, K.M., Johnson, M.W., 2010. Olive fruit fly: managing an ancient pest in modern times. Annu. Rev. Entomol. 55, 151–169.

De Ruiter, P.C., Moore, J.C., Zwart, K.B., Bouwman, L.A., Hassink, J., Bloem, J., Edwards, C.A., Lofty, J.R., 1975. The influence of cultivations on soil animal populations. Progress in Soil Zoology. Springer, Netherlands, pp. 399–407.

European Environment Agency (EEA), 2004. High Nature Value Farmland—Characteristics, Trends and Policy Challenges. Office for Official Publ. of the Europ. Communities, Copenhagen.

Gardiner, M.M., Landis, D.A., Gratton, C., DiFonzo, C.D., O'Neal, M., Chacon, J.M., Wayo, M.T., Schmidt, N.P., Mueller, E.E., Heimpel, G.E., 2009. Landscape diversity enhances biological control of an introduced crop pest in the north-central U.S. Ecol. Appl. 19, 143–154.

Gkisakis, V.D., Kollaros, D., Bàrberi, P., Livieratos, I.C., Kabourakis, E.M., 2015. Soil Arthropod diversity in organic, integrated, and conventional olive orchards and different agroecological zones in Crete, Greece. Agroecol. Sustain. Food 39, 276–294.

Gomiero, T., Pimentel, D., Paoletti, M.G., 2011. Environmental impact of different agricultural management practices: conventional vs. organic agriculture. Cr. Rev. Plant Sci. 30, 95–124.

Gonçalves, M.F., Pereira, J.A., 2012. Abundance and diversity of soil arthropods in the olive grove ecosystem. J. Insect Sci. 12, 1–14.

Grandy, A.S., Robertson, G.P., 2006. Aggregation and organic matter protection following cultivation of an undisturbed soil profile. Soil Sci. Soc. Am. J. 70, 1398–1406.

Hole, D.G., Perkins, A.J., Wilson, J.D., Alexander, I.H., Grice, P.V., Evans, A.D., 2005. Does organic farming benefit biodiversity? Biol. Conserv. 122, 113–130.

Jerez-Valle, C., García, P.A., Campos, M., Pascual, F., 2014. A simple bioindication method to discriminate olive orchard management types using the soil arthropod fauna. Appl. Soil Ecol. 76, 42–51.

Kabourakis, E., 1996. Prototyping and Dissemination of Ecological Olive Production Systems: A Methodology for Designing and a First Step towards Validation and Dissemination of Prototype Ecological Olive Production Systems (EOPS) in Crete. Published PhD thesis. Wageningen Agricultural University, The Netherlands.

Kabourakis, E., 1999. Code of practices for ecological olive production systems. Olivae 77, 46–55.

Kollaros, D., Kabourakis, E., Volakakis, N., Xasourakis, I., Kapetanakis, E., 2006. Impact of different farming practices on the soil fauna of olive groves in Messara, Crete. 10th International Congress on the Zoogeography and Ecology of Greece and Adjacent Regions, Patra, Greece, June 26–30.

Mackey, R.L., Currie, D.J., 2001. The diversity–disturbance relationship: is it generally strong and peaked? Ecology 82, 3479–3492.

Magurran, A.E., 2004. Measuring Biological Diversity. Blackwell, Oxford.

McIntyre, N.E., Rango, J., Fagan, W.F., Faeth, S.H., 2001. Ground arthropod community structure in a heterogeneous urban environment. Landscape Urban Plan 52, 257–274.

Metzidakis, I., Martinez-Vilela, A., Castro Nieto, G., Basso, B., 2008. Intensive olive orchards on sloping land: good water and pest management are essential. J. Environ. Manage. 89, 120–128.

Moonen, A.C., Marshall, E.J.P., 2001. The influence of sown margin strips, management and boundary structure on herbaceous field margin vegetation in two neighbouring farms in southern England. Agric. Ecosyst. Environ. 86, 187–202.

Moonen, A., Bàrberi, P., 2008. Functional biodiversity: an agroecosystem approach. Agric. Ecosyst. Environ. 127, 7–21.

Morris, T., Campos, M., 1999. Predatory insects in olive-grove soil. Zool. Baetica 10, 149–160.

National Statistical Service of Greece, 2009. Agricultural statistics of Greece. Primary Sector Statistics. NSSG, Pireas, Greece.

Neher, D.A., 1999. Soil community composition and ecosystem processes: comparing agricultural ecosystems with natural ecosystems. Agroforest. Syst. 45, 159–185.

Økland, R.H., 1999. On the variation explained by ordination and constrained ordination axes. J. Veg. Sci. 10, 131–136.

Orsini, M.M., Daane, K.M., Sime, K.R., Nelson, E.H., 2007. Mortality of olive fruit fly pupae in California. Biocontrol Sci. Technol. 17, 797–807.

Peres-Neto, P.R., Legendre, P., Dray, S., Borcard, D., 2006. Variation partitioning of species data matrices: estimation and comparison of fractions. Ecology 87, 2614–2625.

Ponce, C., Bravo, C., de León, D.G., Magana, M., Alonso, J.C., 2011. Effects of organic farming on plant and arthropod communities: a case study in Mediterranean dryland cereal. Agric. Ecosyst. Environ. 141, 193–201.

Reichle, D.E., 1977. The role of soil invertebrates in nutrient cycling. Ecol. Bull. 25, 145–156.

Ruano, F., Lozano, C., Garcia, P., Peña, A., Tinaut, A., Pascual, F., Campos, M., 2004. Use of arthropods for the evaluation of the olive orchard management regimes. Agric. For. Entomol. 6, 111–120.

Santos, S., Cabanas, J., Pereira, J., 2007. Abundance and diversity of soil arthropods in olive grove ecosystem (Portugal): effect of pitfall trap type. Eur. J. Soil Biol. 43, 77–83.

Schweiger, O., Maelfait, J.P., Wingerden, V.W., Hendrickx, F., Billeter, R., Speelmans, M., Augenstein, I., Aukema, B., Aviron, S., Bailey, D., Bukacek, R., Diekötter, T., Dirksen, J., Frenzel, M., Herzog, F., Liira, J., Roubalova, M., Bugter, R., 2005. Quantifying the impact of environmental factors on arthropod communities in agricultural landscapes across organizational levels and spatial scales. J. Appl. Ecol. 42, 1129–1139.

Setälä, H., Marshall, V.G., Trofymow, J.A., 1995. Influence of micro- and macro-habitat factors on collemolan communities in Douglas-fir stumps during forest succession. Appl. Soil Ecol. 2, 227–242.

Sharley, D.J., Hoffmann, A.A., Thomson, L.J., 2008. The effects of soil tillage on beneficial invertebrates within the vineyard. Agric. For. Entomol. 10 (3), 233–243.

Shrestha, R.B., Parajulee, M.N., 2010. Effect of tillage and planting date on seasonal abundance and diversity of predacious ground beetles in cotton. J. Insect Sci. 10 174–174.

Šmilauer, P., Lepš, J., 2014. Multivariate Analysis of Ecological Data Using CANOCO 5. Cambridge University Press, Cambridge, UK.

Southwood, T.R.E., 1966. Ecological Methods. Methuen & Co., London, UK.

Stork, N.E., Eggleton, P., 1992. Invertebrates as determinants and indicators of soil quality. Am. J. Altern. Agric. 7, 38–47.

ter Braak, C.J.F., Šmilauer, P., 1998. CANOCO Reference Manual and User's Guide to Canoco for Windows: Software for Canonical Community Ordination (version 4). Microcomputer Power, Ithaca, New York, pp. 352.

ter Braak, C.J.F., Šmilauer, P., 2002. Canoco Reference Manual and CanoDraw for Windows User's guide: Software for Canonical Community Ordination (Version 4.5). Biometris, Wageningen University and Research Centre, Wageningen.

ter Braak, C.J.F., Looman, C.W., 1994. Biplots in reduced-rank regression. Biometrical J. 36, 983–1003.

Urbaneja, A., Marí, F.G., Tortosa, D., Navarro, C., Vanaclocha, P., Bargues, L., Castañera, P., 2006. Influence of ground predators on the survival of the Mediterranean fruit fly pupae, Ceratitis capitata, in Spanish citrus orchards. BioControl 51, 611–626.

Volakakis, N.G., Eyre, M.D., Kabourakis, E.M., 2012. Olive fly *Bactrocera oleae* (Diptera, Tephritidae) activity and fruit infestation under mass trapping in an organic table olive orchard in Crete, Greece. J. Sustain. Agric. 36, 683–698.

Vollhardt, I.M., Tscharntke, T., Wäckers, F.L., Bianchi, F.J., Thies, C., 2008. Diversity of cereal aphid parasitoids in simple and complex landscapes. Agric. Ecosyst. Environ. 126, 289–292.

Ward, M.J., Ryan, M.R., Curran, W.S., Barbercheck, M.E., Mortensen, D.A., 2011. Cover crops and disturbance influence activity-density of weed seed predators *Amara aenea* and *Harpalus pensylvanicus* (Coleoptera: Carabidae). Weed Sci. 59, 76–81.

Wardle, D.A., 1995. Impacts of disturbance on detritus food webs in agro-ecosystems of contrasting tillage and weed management practices. Adv. Ecol. Res. 26, 105–185.

Weil, R.R., Kroontje, W., 1979. Effects of manuring on the arthropod community in an arable soil. Soil Biol. Biochem. 11, 669–679.

Wickings, K., Grandy, A.S., 2013. Management intensity interacts with litter chemistry and climate to drive temporal patterns in arthropod communities during decomposition. Pedobiologia 56, 105–112.

WMO, 1983. Guide to meteorological instruments and methods of observation. WMO-No. 8. World Meteorological Organisation, Geneva.

Wurst, S., 2013. Plant-mediated links between detritivores and aboveground herbivores. Front. Plant Sci. 4 (380).